NATIONAL RADIO INSTITUTE

Certified Radio-Trician's Course
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NRI

TETRODE, PENTODE AND VARIABLE MU TUBES

No. 18FR

Originators of Home Study Radio Courses
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Happy is the man that findeth wisdom
And the man that getteth understanding
For the gaining of it is better than the gaining of silver,
And the profit thereof than fine gold.

—*Proverbs.*

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THE PURPOSE OF THE SCREEN GRID

In a previous lesson the subject of internal tube capacity and its effects—regeneration and self-oscillation—was briefly mentioned in connection with triodes. You will remember we spoke about the capacity existing between the grid and plate of a triode. In other words, the grid and plate of the tube act as two plates of a small condenser. If we had a triode with absolutely no internal capacity, we could obtain the same effect by connecting a 6 micro-microfarad (.000006 mfd.) condenser across the grid and plate externally.

Through this capacity a certain amount of the A.C. signal voltage in the plate circuit of an amplifying tube can feed back to the grid where it combines with the incoming signal voltage. This in itself is not necessarily a disadvantage for it serves to increase the signal strength and so increases the apparent amplification. Practically all of the older broadcast receivers made use of the principle of regeneration to increase sensitivity, and for short wave reception, regeneration is almost essential.

But, as was also mentioned previously, excessive regeneration will cause the amplifier tube to oscillate and the desired signal is "killed." And so we can see that amplification is definitely limited, for when regeneration reaches a certain point the tube will oscillate.

It is largely because of this that the amplification factor (μ) of most triodes is not higher than 8 or 9.

Consider the circuit in Fig. 1. An incoming signal is impressed across the grid and cathode (filament) of the first tube. This signal is amplified and is passed on to another tube circuit.

Tube *A* will have a grid-to-plate capacity of about 6 micro-microfarads and part of the signal voltage in the plate circuit will feed back to the grid through this capacity. Thus the circuit will be a very efficient amplifier up to the point where self-oscillation sets in—that is, at the point where the feed-back voltage is larger than the signal input voltage.

Let us say that one-hundredth of the output gets back into the input through the grid-to-plate capacity. This adds to the

signal voltage impressed on the grid and as the tube cannot discriminate between a new signal and an old one amplified by itself, it is reamplified and again appears in the output. Then one-hundredth of this new increased A.C. output feeds back, increasing the grid signal voltage still further. This process of feed-back and reamplification continues until the tube oscillates, unless some method of stabilization is used to prevent oscillation.

Of course, feed-back from the plate to the grid circuit can take place through any inductive or capacitive coupling between the two circuits. For example, if the field about the output transformer or coil can link with the field of the input transformer (grid coil), there will be inductive feed-back. This would be equivalent to the circuit shown in Fig. 2a where a tickler coil (shown in dotted lines) serves to feed back energy from the plate to the grid circuit.

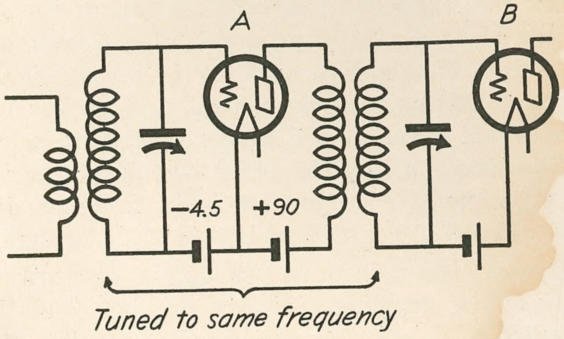

Fig. 1

In the same way, any capacity between wiring or metal parts will cause a feed-back. This would be equivalent to the circuit shown in Fig. 2b where a condenser is shown (in dotted lines) connected across the plate and grid of the tube.

In regenerative receivers the inductive method of feed-back is usually used in the detector circuit. Then the tickler is made variable or some other method of controlling regeneration is used.

However, in non-regenerative receivers and even in the R.F. stages of regenerative receivers, feed-back is undesirable and where triode tubes are used, special precautions are taken to prevent feed-back through the tube capacity, and to prevent any inductive or capacitive coupling between wiring and parts. Methods of neutralization and stabilization are employed (these

will be taken up in later lessons), coils are spaced far apart and grid and plate circuit wires are kept away from each other.

Now getting back to the internal capacity of a triode—it should be clear that if we could reduce the capacity existing across the grid and plate, we could increase its amplifying prop-

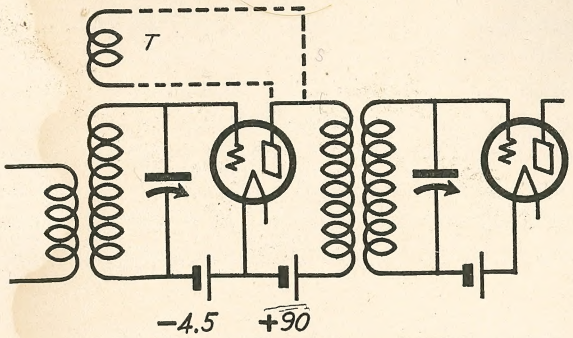

Fig. 2(a)

erties. The maximum amplification possible with a triode is 30—in the case of the '40 type tubes—but '40 tubes can only be used as A. F. amplifiers. They oscillate much too readily for use in R.F. stages. It was known for a long time that if this internal capacity could be eliminated, tubes could be constructed to have high amplification factors. The result of efforts to reduce

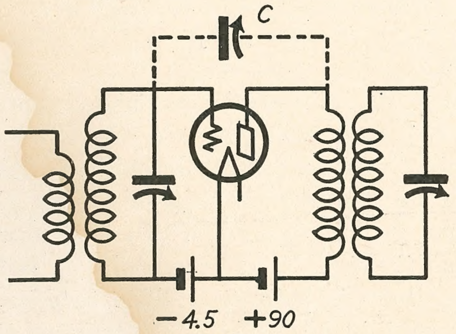

Fig. 2(b)

this internal capacity was the screen grid tube. And now that screen grid tubes are so well known and their operation is so clearly understood, it seems strange that the solution was not thought of long ago.

By a suitable arrangement of the elements of a tube it is possible to increase its amplification almost indefinitely but the

inter-electrode capacity which would remain almost the same would become so much more effective in feeding back R.F. energy that a high mu triode could not be used for R.F. amplification. Any increase in the amplification factor of a tube will make it more susceptible to R.F. feed-back, i. e., while a type '01A tube requires 1/8 ($\mu = 8$) of the total A.C. plate voltage energy to sustain oscillation by feed-back, a type '40 tube requires only 1/30 ($\mu = 30$) of this.

Of course if 1 volt A.C. on an '01A grid will produce 8 volts A.C. in the plate circuit and its internal capacity is capable of feeding back 1 volt which will in turn build up another 8 volts A.C. in the plate circuit, oscillation will be sustained. Under similar operating conditions 1 volt in a type '40 tube will produce 30 volts in the plate circuit which will feed back $30 \div 8$ or

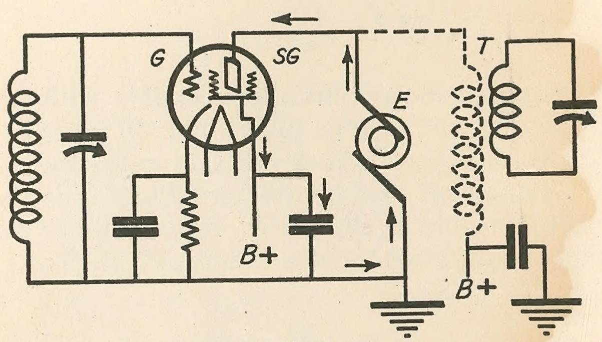

Fig. 3

$3\frac{3}{4}$ volts because its inter-electrode capacity is practically the same. These $3\frac{3}{4}$ volts will produce $3\frac{3}{4} \times 30$ or $112\frac{1}{2}$ volts A.C. in the plate circuit and the tube will oscillate very readily.

In the tetrode (the screen grid tube) the plate is shielded from the control grid by a screen, which is now known as the screen grid, and the grid-to-plate capacity is reduced to almost nothing. Thus there is extremely little feed-back through the tube and no possibility of oscillation to hamper the operation of the tube.

Now let us see how the shielding effect of the screen grid prevents feed-back from the plate to the grid circuit. Figure 3 shows a screen grid tube connected as an R.F. amplifier. However, in place of the primary of an output transformer, we have connected a small generator *E* which we are going to assume supplies an A.C. voltage corresponding to the feed-back voltage

in a triode circuit. The arrows show what happens. The "feed-back" voltage goes through the plate to the screen grid, through a by-pass condenser to the ground.

But what about the grid circuit? Practically no feed-back voltage gets to the grid and what does get back is so little that

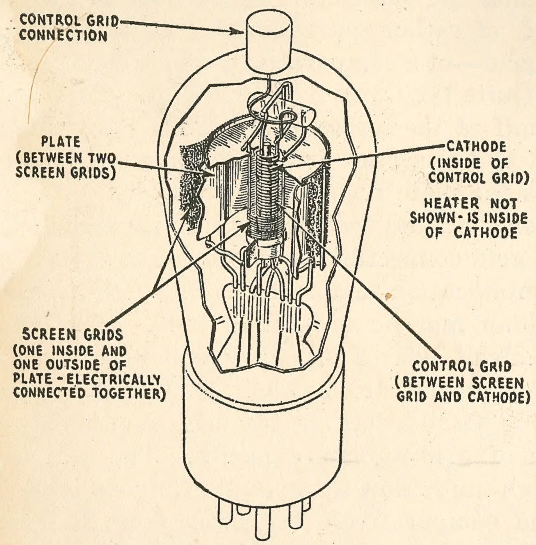

Fig. 4—Cross-sectional view showing the construction of an A.C. screen-grid vacuum tube.

it can usually be neglected. The grid-to-plate capacity of a tetrode (.006 $\mu\mu$f.) is one-thousandth that of a triode and it would take 1000 times as much feed-back to cause self-oscillation as in a triode.

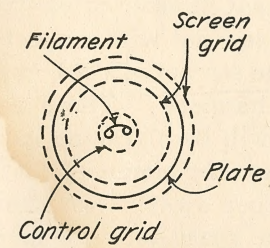

Fig. 5—Looking down into a screen grid tube showing how the elements are placed.

SCREEN GRID TUBE CONSTRUCTION

Figure 4 shows a cut-away view of an A.C. screen grid tetrode, from a study of which many of the constructional details can be learned. Figure 5 is a drawing of the elements, looking

down on the tube, which shows the positions of the various electrodes.

In the very center is the filament which is nothing but a single, fine resistance wire threaded through a porcelain cylinder and turned back on itself. The cathode is a metal tube which is pressed onto the porcelain. Quite close to the cathode is the control grid, of rather coarse metal mesh. Then comes half of the screen grid—at a comparatively short distance from the control grid. Quite far away from this is the plate and then comes the other half of the screen grid. Thus the plate is practically surrounded by the screen grid. The internal half of the screen grid shields the plate from the control grid. The external half of the screen grid and the connecting disc shield the plate from the control grid connection to the cap of the tube.

The amplification factor of a screen grid tetrode used as an audio amplifier may be as high as 1000. Used as an R.F| amplifier it is about 400. This is a considerably greater amplification factor than any triode has. One of the reasons why the greater mu is possible has already been mentioned—the practical elimination of grid-to-plate capacity. The real explanation of the very high mu is that the grid in a tetrode is very close to the cathode and comparatively far away from the plate, a factor which makes for large amplification. There is also another reason for this high amplification factor which requires a bit more explanation.

When an electron leaves the cathode, it shoots toward the plate. But just as soon as the filament loses one negative charge, it is less negative (more positive) by that amount. It can be seen then that if a great number of electrons leave the filament, it may be quite positive—not with respect to the plate of course, but with respect to the stream of electrons that are on their way to the plate. What happens? Those electrons that are quite close to the cathode will be attracted back to the cathode, just about as much as they are attracted to the plate, which, while more positive, is farther away. Not knowing which way to go they congregate in the space between the cathode and plate in a sort of cloud. This negative cloud then tends to retard other electrons on their way from the cathode to the plate.

The effect of these electrons that don't know where to go is called the *space charge*. Very frequently the name is extended to apply to the cloud of electrons itself. Because of the space charge, not all the electrons emitted from the cathode get to the

plate, and the grid which is between the filament and the plate cannot control the electron flow as it could if this space charge of "loafer" electrons did not exist.

In the screen grid tube provisions are made to get the "loafer" electrons moving. The method used is simple—a positive charge is placed on the screen grid—about one-third of the D.C. plate voltage. Then the electrons emitted from the cathode will be very strongly attracted to the screen grid. They feel the effect of both the plate and the screen grid which is closer to the cathode than the plate. Most of the electrons, however, do not flow through the screen grid circuit—they fly directly through the openings in the screen, to the plate. Thus the screen grid acts as a sort of "puller," helping the electrons over to the plate. It puts the "loafer" electrons to work.

The result is a steady stream of electrons from the cathode to the plate—the grid can control *all* the electrons emitted—and we obtain maximum amplification.

It must be remembered however, that while the screen is at a relatively high D.C. potential—it is at ground potential as far as radio frequency currents are concerned—it is connected to ground through an R.F. by-pass condenser. In this respect (as far as R.F. is concerned) it is at the same potential as the cathode, for it, too, is grounded. It is very important that you understand the distinction between D.C. potential and R.F. potential. The screen is operated at a D.C. potential of about one-third of the potential of the plate in order to overcome the effect of the space charge. It is at ground R.F. potential to prevent grid-to-plate capacity and regenerative feed-back.

If it were not for the space charge effect resulting in low amplification and tube inefficiency the screen would require no D.C. voltage and could be connected directly to the cathode. It would be just as effective in reducing inter-electrode capacity without a D.C. potential. But by placing on the screen a rather high D.C. potential and at the same time by-passing it to ground we make it serve two purposes—eliminating tube capacity and space charge effects.

Very obviously, since tube manufacturers have gone to so great trouble to build a tube which has negligible grid-to-plate capacity, precautions must be taken to prevent feed-back from the plate circuit to the grid circuit through circuit wiring and between parts. It is for this reason that shielding is so essential in screen grid circuits. To prevent coupling between circuit con-

nections, leads are made as short as possible. Coils are placed in copper shielding cans. The screen grid tubes themselves are covered with metallic shields and in many circuits even the gang condenser is placed in a metal box to prevent undesired coupling.

What would happen if there were some plate-to-grid coupling? In a screen grid receiver with three stages of screen grid R.F. amplification, the voltage amplification may be about 30,000 times. Thus the least part of the R.F. voltage in the output of the last tube which gets back into the input of the first tube will reappear in the output amplifier 30,000 times. Clearly the expense and care that manufacturers go to in order to shield all the parts in a screen grid stage is justifiable.

SCREEN GRID TUBE PERFORMANCE

By this time you should be quite accustomed to getting an insight into the performance of a device from a study of its characteristic curve. In considering the performance of screen grid tubes we are going to start out with a study of the plate voltage-plate current (E_p-I_p) characteristic curves of one type of tube.

In Fig. 6 you will find a family of static E_p-I_p characteristic curves for the UY-224 screen grid tube. Notice that there are five E_p-I_p curves, taken for various grid bias voltages. The sixth curve which looks very much like one of the others but reversed, is the curve of screen grid current, taken with 1½ negative volts on the control grid.

Now let's see what these curves tell us. Forget about the screen grid current curve for the moment. The other curves show us that when the plate voltage is lower than the screen grid voltage (less than 75^v), electrons will actually flow from the plate to the screen grid (indicated by the portions of the curves below the zero current line) and that this electron flow may be as high as 1 milliampere. As the plate voltage is increased, however, plate current increases very rapidly up to a point where the plate voltage is about 15 volts higher than the screen grid voltage. And any increases in plate voltage beyond 90^v result in rather small increases in plate current.

The explanation of electron flow from plate to screen grid is interesting. Let us say an electron is emitted from the cathode with sufficient force to carry it past the control grid. Here it encounters the positive field produced by the screen. But the

attraction of the screen is so great that the electron gains sufficient speed to go right through the meshes of the screen. If there is a very low positive voltage on the plate, let us say 5 volts, immediately the electron gets past the screen it will feel a mild attraction to the plate and a stronger attraction back to the screen. Which way it will go is a question. From our curve, and this time considering the screen grid current curve along with the others, we might say that out of five electrons, four go back to the screen and one goes on to the plate.

But what happens if the plate is, let us say, 35 volts positive —with no bias on the grid? Now there is a greater attraction

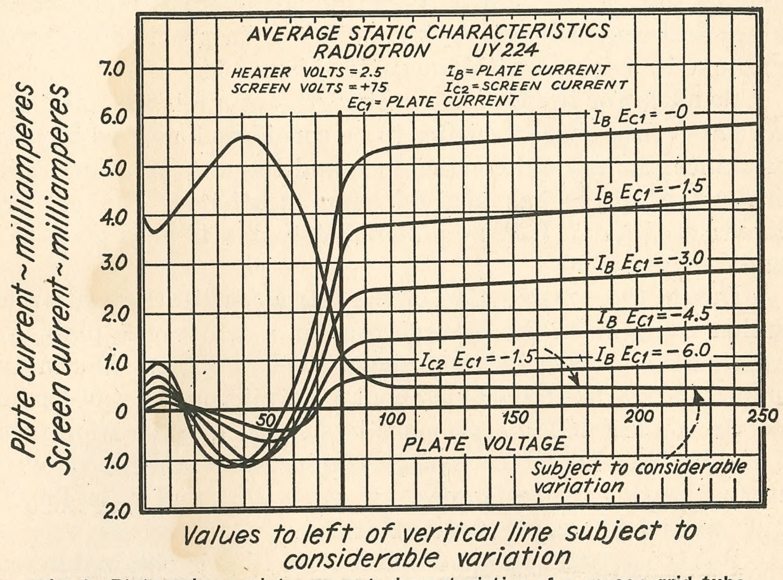

Fig. 6—Plate volume-plate current characteristics of a screen grid tube.

to the plate and the electrons that pass through the screen grid strike the plate with greater velocity. As the electrons bombard the plate, they may bounce back—they may even knock other electrons off the plate. As the screen grid is more positive than the plate, the chances are that instead of returning to the plate they will move back to the screen grid—and we have considerable screen grid current flow. In effect then, the plate acts as a second cathode as it emits electrons. For this reason we call this current flow "secondary emission" current. From the curves we can see that with 45 volts on the plate and 75 volts on

the screen we have a screen grid current flow of 5½ ma. and a plate current flow, *in the negative direction* of about 1 ma.

The electrons that return to the screen grid from the plate are the result of "secondary emission." However, when the screen grid tube is supplied with the proper operating voltages there is very little secondary emission and almost all of the screen grid current that flows is due to those electrons which strike against the metal of the screen grid and do not pass through the openings.

As the plate voltage is increased there is less and less screen grid current flow. In practice it is usually considered negligible.

As far as the effect of grid bias is concerned, these curves show us that as the bias is increased the average plate current values decrease, which is as it should be. In practice the screen grid tube is operated with a negative bias of 1½ volts.

So much for the E_p-I_p characteristics of a tetrode tube. Now there are other characteristics to be considered such as the plate resistance, the mutual conductance and the amplification factor. The last of these has already been mentioned—the mu of a tetrode used as an R.F. amplifier is 400, and if used as an A.F. amplifier it is 1000.

Due to the construction of the tetrode, with the plate much farther away from the cathode than in a triode, the plate A.C. resistance is extremely high, about 400,000 ohms. The mutual conductance of the tetrode is about 1000 micromhos (.001 mho).

As you learned in a previous lesson, the amplification factor of a tube is equal to the mutual conductance multiplied by the internal plate A.C. resistance. If g_m is .001 and r_p is 400,000, "mu" will be 400 as previously stated.

But the actual voltage amplification that is obtainable from a tube depends on the plate load A.C. resistance. For maximum obtainable voltage amplification the A.C. resistance of the plate load should be from 6 to 8 times the tube plate A.C. resistance. This would mean that to take advantage of about 90% of the mu of the screen grid tube we would have to use a 3 megohm impedance in the plate circuit.

In an R.F. amplifier where transformer or inductive coupling must be used, it is impossible to build up a plate load impedance of much more than 100,000 ohms. In practice the total inductive reactance in the plate circuit of a screen grid R.F. amplifier may be considerably less than 100,000 ohms. Consequently the voltage amplification of a screen grid R.F. tube will

be much less than the mu of the tube, possibly about 50 to 80 at the most. Then only one-eighth to one-fifth of the mu of the tube is used. Even considering this, however, the R.F. amplification of a screen grid tube is about ten times that of an ordinary triode.

From this discussion of the performance characteristics of a screen grid tube, it might seem that we could make one screen grid stage of R.F. amplification do the work of three or four triode stages. And yet in screen grid receivers we find as many R.F. stages as in receivers which use triodes as R.F. amplifiers.

If all the radio frequency stages had to do was to amplify, we could use a single screen grid tube instead of three or four triodes. But the R.F. section must not only amplify, it must

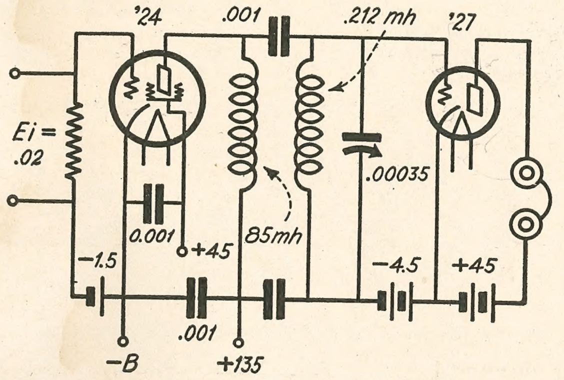

Fig. 7—A stage of screen grid R.F. working into a triode C bias detector.

select the signals. Let us see what would happen if we had only one stage of screen grid amplification before the detector as in Fig. 7. We will get very loud signals from local stations but selectivity will seem very poor. Actually the selectivity may be better than if a single triode were connected in a similar circuit, but the apparent selectivity is much less. Why?

Refer to the lower curve in Fig. 8 which is the resonance curve of a triode. Notice that signals 10 kc. off the resonant frequency will not be amplified and selectivity is apparently very good. But let us say the amplification of a screen grid tube is 10 times that of a triode and its response curve is as represented by the upper curve. In this case all signals 20 kilocycles off the resonant frequency will be amplified and selectivity is apparently decreased.

This is the reason why just as many tuned circuits are necessary in a screen grid receiver as in a receiver using triode tubes in the tuning stages. A good selectivity characteristic is absolutely essential in modern receivers. The chief advantage in the use of screen grid tubes in the R.F. section is the increased sensitivity. With the use of screen grid tubes, weak signals can be brought in full volume—signals that would be unheard if triodes were used. Or if we are not interested in distant stations or

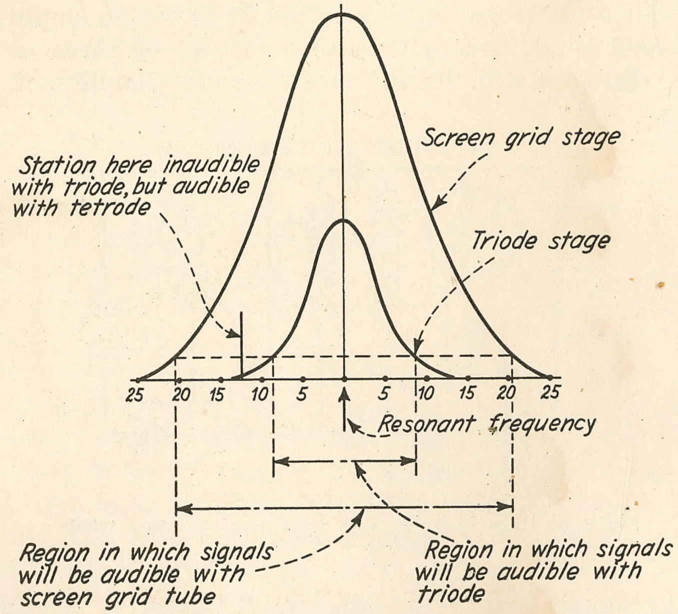

Fig. 8—Graph illustrating how increasing the gain of a single stage seems to decrease the selectivity.

large volumes, we can use a much smaller antenna with a screen grid receiver and eliminate a great deal of noise and interference.

In midget receivers where a great deal of amplification must be crowded into a small space, one screen grid R.F. tube is actually made to do the work of several triodes. That is the set is so designed that one screen grid tube provides all the R.F. amplification necessary, and selectivity is provided for by the use of a band-pass tuner ahead of the R.F. tube. In full sized receivers, even though band-pass tuning is provided for, there are several stages of screen grid R.F. amplification, for maximum sensitivity.

COUPLING SYSTEMS USED IN SCREEN GRID AMPLIFIERS

In R.F. systems consisting of several screen grid tube stages, the individual tubes are coupled together either by transformers or by choke coils and condensers. Most receivers of the tuned radio frequency type use from two to four screen grid stages before the detector which may be a triode or a tetrode. Superheterodynes have one or two screen grid amplifiers working at the carrier frequency, and two to three screen grid stages for intermediate frequency amplification. Following the inter-

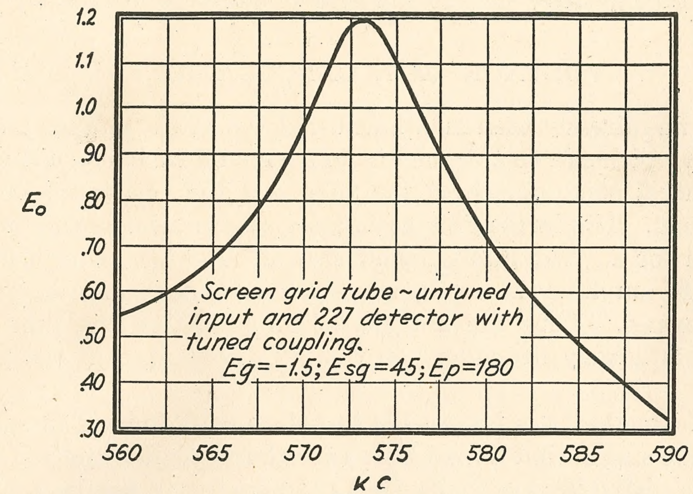

Fig. 9

mediate frequency amplifier is a triode or tetrode second detector after which comes the audio amplifier.

Transformer coupling is generally preferred to choke coil coupling because of simplicity of wiring and construction, greater economy and somewhat greater amplification and selectivity.

From what has been said previously, it should be clear that the actual voltage amplification obtained from a screen grid stage is largely dependent on the type of coupling used. This also plays a large part in determining selectivity. In Fig. 9 will be found an experimental determination of the selectivity of a single screen grid stage. In this case the tube was coupled to a detector through a high inductance choke and a blocking condenser. It will be noted that the voltage gain at 10 kc. off

resonance is about one-half that at resonance. In other words there is not much selectivity.

If two stages were used, at 10 kc. off resonance the signal would drop to about one-fourth the value of the signal at resonance, and the selectivity would be doubled.

The actual voltage gain in this stage is the output voltage (1.2 volts) at resonance, divided by the input voltage (.02 volt) or about 60 times. If transformer coupling were used, somewhat greater amplification would result. In practice, transformers almost always are used. Another advantage in the use of transformer coupling is that there is less possibility of hum voltages in one tube getting back to the grid of the previous tube.

VOLTAGE GAIN CALCULATIONS

It has already been mentioned that the actual voltage amplification which can be obtained from a vacuum tube depends upon the mutual conductance of the tube and the resistance of the plate load. The larger this resistance, the greater is the amplification for a given mutual conductance. But the plate load on an R. F. amplifier is a coil, usually the primary of a coupling transformer. Thus the amount of amplification the tube can supply is largely dependent on the A.C. resistance of the plate coil.

In practice it is impossible to obtain coils for use in screen grid tube stages that have a high enough impedance and yet have so little distributed capacity that the signal will not be shorted out. For this reason the gain of an R.F. screen grid stage is rarely over 40 to 80 times. In actual screen grid receivers, the voltage gain per stage is between 30 and 50 where several stages are used and in midget receivers where only one or two R.F. stages are used and a great deal of amplification must be obtained from a single stage, the gain may be as high as 60 or 80 per stage.

In the intermediate frequency amplifier of a superheterodyne receiver we can get the screen grid tube to work at much higher efficiency. In some cases the gain per stage is as high as 300 at 175 kc., although gains as large as this are not usual. The reason for this is that an intermediate frequency amplifier is designed to resonate at a single frequency and its band width need be only 10 kc. It has no moving parts, it can be carefully shielded at the factory, it has no large parts that are more or

less exposed (which might serve as couplings between adjacent stages). Therefore, a high impedance load can be placed in the plate circuit and a much larger portion of the mu of the tube utilized.

Suppose a load impedance at 175 kc. (the intermediate frequency) is made equal to the resistance of the tube. The actual voltage amplification of the tube will be about 200, that is, one-half the mu of the tube. However, any increase in load impedance above this amount will not result in a proportional increase in voltage amplification. Remember that if the plate load impedance is 6 to 8 times the internal resistance of the tube, the voltage amplification will be only about 90% of the mu of the tube.

Now let us stop a moment and review the requirements that must be fulfilled by a good vacuum tube amplifier. In the radio frequency section we naturally want maximum amplification. If we use triode tubes which have a comparatively low internal resistance, we can easily make the plate load several times as large as the tube resistance and obtain almost the entire mu of the tube. But as the mu of an ordinary triode is only 8 or 9, even maximum amplification will not be very large.

On the other hand when we use screen grid tubes that have a very high internal impedance, it is impossible to have a plate load many times this value, so we use as large a plate impedance as we can and leave it up to the high amplification factor of the tube to provide the needed amplification. Even with a comparatively low plate A.C. resistance, a voltage amplification of 30 to 50 is obtained.

In the I.F. amplifier the difference between the screen grid tube and the ordinary triode is much more pronounced. Even if we used '40 tubes, the maximum voltage gain per tube would be less than 30. But when screen grid tubes are used as I. F. amplifiers, the gain per tube may be as high as 300, as previously mentioned.

THE SCREEN GRID TUBE AS AN AUDIO AMPLIFIER

While the screen grid tube is essentially an R.F. amplifier, it can be made to amplify at audio frequencies as has been made evident by the development of the Loftin-White circuit.

The screen grid tube used in a conventional audio system is not very satisfactory. Let us see why. The effect of the plate

load resistance on voltage amplification has been stressed in this lesson. When used as an audio amplifier, the screen grid tube should feed into a plate load of about 250,000 ohms. Then the voltage drop across this resistor will reduce the voltage on the plate of the tube considerably and amplification falls off.

The Loftin-White circuit is a rather successful attempt to make use of the screen grid tube as an audio amplifier. It is a so-called "direct coupled" amplifier because there is no condenser between the plate of one tube and the grid of the following tube as in a resistance coupled amplifier. The basic circuit is shown in Fig. 10. The plate of one tube is connected directly to the grid of the following tube. The resistor R_c is the plate supply resistor and provides the load impedance. The sum of the volt-

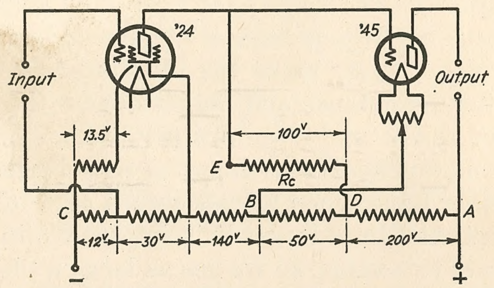

Fig. 10—Circuit showing direct coupled audio amplifier.

ages necessary for the two plate circuits and the two grid biases must be supplied to the terminals of the resistors between *A* and *C*. If *A* is the positive end, then as we progress toward *B* the voltage becomes more and more negative. Thus at *B* the voltage may be 250 volts negative with respect to *A*. This means that the '45 tube plate is 250 volts positive with respect to point *B* and the '45 filament. Point *E* is 50 volts negative with respect to *B* and so the grid has a negative bias of –50ᵛ. *D*, however, is 232 volts more positive than *C* and so the plate of the first tube is 232 volts positive, and so on.

It is obvious that a very high supply voltage is required, which is usually considered a disadvantage. The chief advantage of this system is that no distortion can be introduced into the signal by the coupling—which is nothing but a short heavy "jumper" wire with practically no inductance.

THE SCREEN GRID TUBE AS A SPACE CHARGE AMPLIFIER

Some few fairly successful attempts have been made to use present types of screen grid tubes as space charge audio amplifiers. When operated as a space charge amplifier a positive D.C. potential is put on the control grid of the tube and the screen grid is made to act as the control grid—that is, the input is fed directly to the screen grid instead of to the control grid.

Then the positive potential on the inner grid tends to overcome the effect of space charge and the electrons emitted from the cathode are speeded up on their way to the plate. The screen grid which is now the control grid regulates the number of electrons that actually reach the plate in accordance with the signal voltages impressed on it.

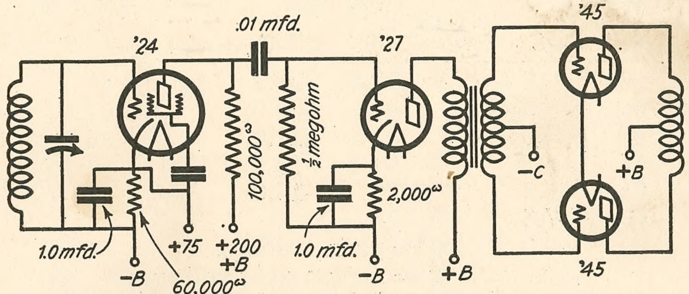

Fig. 11—Circuit of a screen grid detector working into a push pull power stage through an intermediate amplifier.

Operating a screen grid tube in this manner changes its characteristics considerably. The internal impedance is naturally made smaller and so is the mu—the theoretical maximum amplification obtainable—because the control grid is now much closer to the plate.

In practice it has been found that a '22 type tube used as a space charge amplifier will have a plate impedance of about 125,000 ohms and an amplification factor of approximately 100. Of course the amount of actual amplification that can be obtained is dependent on the A.C. resistance in the plate circuit.

The space charge amplifier has the advantage that it can take a weak audio signal and amplify it considerably, but it also has the disadvantage that amplification falls off above 2000 cycles due to the capacity between the plate and the screen grid,

so that while low frequency response is good, high frequency response is rather poor.

It may be that special tubes will be developed for use as space charge amplifiers which will not have the disadvantage of poor high frequency response. The main difficulty with the present screen grid tube used in this manner is that the spacing of the elements does not permit uniform audio response.

THE SCREEN GRID TUBE AS A DETECTOR

In many modern receivers the screen grid tube is used as a detector feeding into a '27 tube which in turn feeds into a push-pull amplifier using '45 tubes, through a transformer coupling.

TABLE NO. 1

Type 224			*Type 222*			*Type 232*		
Ep	Esg	Eg	Ep	Esg	Eg	Ep	Esg	Eg
180	25	–2.5	135	22.5	–4.5	135	45	–3.0
"	35	–3.5	"	45	–9.0	"	67.5	–5.0
"	45	–4.5	"	55	–11.0	"	90	–8.0
"	55	–5.5	"	67.5	–13.5			
"	65	–6.5	"	75	–15.0			
"	75	–7.5						
250	90	–9.0						

Ep = plate voltage.
Esg = screen grid voltage.
Eg = C bias voltage.

The usual value of plate voltage on the screen grid detector is 180 with a C bias of –7. The plate load impedance is usually about 100,000 ohms. See Fig. 11.

This system will do about the same amount of work as a '27 tube with a C bias of –20 volts and 180 volts on the plate, or a C bias of –30 with 250 volts on the plate (see Fig. 12).

To deliver a large enough voltage swing to load up the push-pull '45's, a '27 detector would require from 20 to 30 peak volts on its grid. On the other hand, the screen grid detector will load up the '45's through an intermediate '27 stage with only 7 peak volts on its grid. This increase in gain is obtained at the cost of an additional '27 tube between the detector and the push-pull stage but it eliminates some R.F. amplification before the detector.

The screen grid tube, like the triode, is universally used as a C bias detector in modern broadcast receivers. Only in amateur sets or in special cases is the grid leak and condenser detector used.

In Table No. 1 various operating voltages for the different types of screen grid tubes when used as detectors, are given.

THE POWER PENTODE

While a screen grid tube is an extremely efficient R.F. amplifier and detector, and a fairly good audio amplifier it cannot be used as a power output tube. Let us see why. Suppose a signal voltage of 3 volts is fed to the grid of a screen grid tube and this is amplified by the tube 75 times. The result is a signal plate voltage of 225 volts. With 250 volts on the plate and 25 volts on the screen grid, it is evident that the instantaneous plate

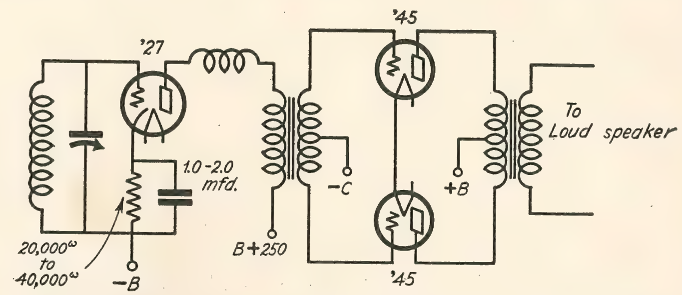

Fig. 12—Circuit of a '27 detector working into a push pull stage.

voltage values may be 475 at one time and 25 volts at another. When the instantaneous plate voltage is 25, there will be considerable secondary emission—that is, a considerable flow of electrons from the plate to the screen grid resulting in distortion.

In addition to this the plate load impedance on a screen grid tube should be extremely high. Therefore the power output obtainable from a screen grid output tube would be very low.

Triode output tubes are very satisfactory but their amplification factors are low—3.5 for a '45 tube. Therefore designing engineers set out to design a tube that would incorporate the advantages of the screen grid tube (high amplification factor) and still be capable of supplying a large undistorted power output. The result was the A.F. pentode.

This pentode has an additional grid, which is connected to the cathode (and so is at ground potential), between the plate and the grid which corresponds to the screen grid of a screen

grid tube. It is called the "cathode grid." Secondary emission electrons from the plate are prevented from getting to the screen grid by the cathode-grid which is highly negative with respect to the plate. Any electrons that leave the plate are instantly

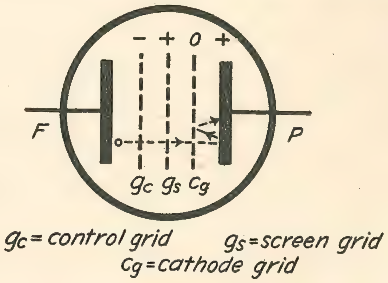

Fig. 13—Illustration showing how the three grids of a pentode tube are arranged.

attracted back to it. Due to the practical elimination of secondary emission effect, the distortion due to secondary emission is eliminated.

In addition to this the tube is so designed that maximum undistorted power output is obtained when the tube feeds into

TABLE NO. 2

American A.F. Pentode Tubes

	Tube Types 247	238	233
Filament voltage	2.5 volts	6.3 volts	2.0 volts
Filament current	1.5 amperes	0.3 amperes	0.26 amperes
Plate voltage	250	135	135
Screen voltage	250	135	135
Grid voltage	–16.5	–13.5	–13.5
Plate current	32 ma.	8 ma.	14 ma.
Screen current	7.5 ma.	2.5 ma.	3 ma.
Plate resistance	38,000 ohms	110,000 ohms	45,000 ohms
Mutual conductance	25,000 micromhos	900 μ mhos	1,400 μ mhos
Amplification factor	95	100	63
Load resistance	7000 ohms	15,000 ohms	7,500 ohms
Power output	2.5 watts	.375 watts	.650 watts

an impedance equal to approximately ¼ the internal impedance of the tube. Thus the load impedance for maximum undistorted output need be only about 5000 ohms.

In an audio tube the matter of internal capacity is relatively unimportant as the capacity would have to be very large to per-

mit audio feed-back. Therefore there is no shielding grid on the outside of the plate, and the grid which corresponds to the inner half of a screen grid in a screen grid tube serves merely to overcome space charge effects. It is kept at a potential equal to the potential of the plate.

Because the A.F. pentode has a high amplification factor and a high plate resistance (as compared with power triodes) it is a very sensitive power tube. Pentodes now on the American market deliver about the same maximum undistorted power output as a triode operated with the same plate voltage, but require

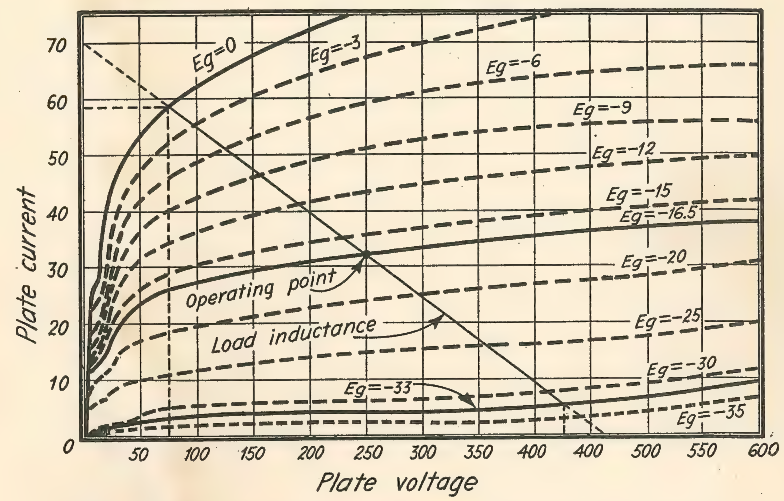

Fig. 14—Plate current characteristics of a modern power pentode.

only ¼ as much grid A.C. voltage because of their high amplification constant. See Table No. 2 for operating characteristics.

Many receivers now on the market employ pentode tubes in the output—in some receivers you will find two pentodes in push-pull—and in many cases, the detector feeds directly into the output stage.

The pentode is an especially valuable development for use in midget receivers where space is at a premium and it is necessary to use as few stages as possible. In some of the more recent midget receivers the detector feeds directly into a single pentode which provides all the audio amplification needed for the operation of the loudspeaker.

THE PROPER LOAD RESISTANCE FOR AN A. F. PENTODE

It has been mentioned that for maximum undistorted output a pentode should work into a load resistance approximately 1/4 that of the tube resistance. Now we are going to see how a radio engineer would go about determining the exact load impedance which should be used.

First he will get a family of plate voltage-plate current curves like those shown in Fig. 14. Then he will locate on the graph, the operating point set by a definite grid bias and plate voltage. In our calculations we are considering a 250 volt plate voltage and a grid bias of –16.5 volts.

It is clear that the grid can swing just 16.5 volts either side of the bias value without becoming positive and for minimum distortion there must be the same change in plate current for a 16.5 volt negative swing as for a 16.5 volt positive swing. If we draw a straight line through the operating point that will cut both the $E_g = zero$ and the $E_g = -33$ volt lines in such a way that both halves of the line are equal, this line will represent the correct impedance. Now all we have to do is to find the numerical value of this load impedance.

TABLE NO. 3

Load Resistance Ohms	*Second Harmonic %*	*Third Harmonic %*	*Watts Output*
4,000	3.9	3.8	2.15
6,000	1.7	5.4	2.60
8,000	1.7	6.7	2.8
10,000	5.5	8.0	2.77
12,000	10.9	9.0	2.62
16,000	17.8	9.3	2.40

We know that load impedance is equal to the A.C. plate voltage divided by the A.C. plate current component ($E_p \div I_p$). We extend our straight line to the edges of the graph. As you will see from Fig. 14, the line now cuts the plate voltage line at about 465 volts and the plate current line at about 71 ma. Dividing 465 by 71 we get approximately 6500 ohms which is very close to 1/4 the internal resistance of the tube.

What would happen if a higher resistance were used and the portion of the line below the operating point would be longer than that above the operating point? For a given signal voltage there would be a greater increase in plate voltage on the positive half cycle than a decrease in plate voltage for the negative half cycle and distortion would result.

In Table No. 3 you will find data on distortion in relation to various values of load resistance as well as relation between power output and load resistance. It can be seen from this table that of the load resistances considered, 6000 ohms would give the maximum undistorted output.

It will be noted that the power output is fairly constant irrespective of the load resistance, which is not at all like the relation between these two factors in a triode circuit. When a triode is used as a power output tube and the resistance of the loudspeaker varies considerably, the power fed to the speaker will vary proportionately. However, in a pentode circuit, the impedance of the speaker may vary appreciably without affecting output power very much.

TABLE NO. 4

Average Characteristics of A.C. Pentode

	(1)	(2)	(3)	(4)
Heater volts	2.5	2.5	2.5	2.5
Heater amperes	1.75	1.75	1.75	1.75
Control grid volts	–1.5	–1.5	–1.5	–1.5
Space charge grid volts	+10	20	10	20
Screen grid volts	+180	180	135	135
Plate volts	250	250	250	250
Amplification factor	575	540	740	750
Plate resistance—ohms	285,000	100,000	380,000	300,000
Mutual Conductance—micromhos	2,000	3,000	1,930	2,500
Plate current MA	4.1	6.0	1.7	2.6
Screen current MA	0.8	0.9	0.5	0.2
Space charge current MA	3.0	10.0	5.0	12.0

R. F. PENTODES

An R.F. pentode has recently been developed but as yet this kind of tube has not found commercial application. In appearance it is very much like the '24 type of screen grid tube, the plate being shielded by a double screen grid, one-half outside the plate and the other half between the plate and the control

grid. The only difference is that there is a space charge grid surrounding the cathode.

The order of the elements is as follows: A standard indirectly heated cathode, a space charge grid surrounding the cathode, a control grid, plate, and the screen grid, half between the control grid and the plate, with the extension outside the plate.

The base of the R.F. pentode is a standard 5-prong base, just like that of the '24 tube. The space charge grid contact is on the side of the base shell.

The average characteristics of a typical R.F. pentode for various operating voltages are given in Table No. 4. You will

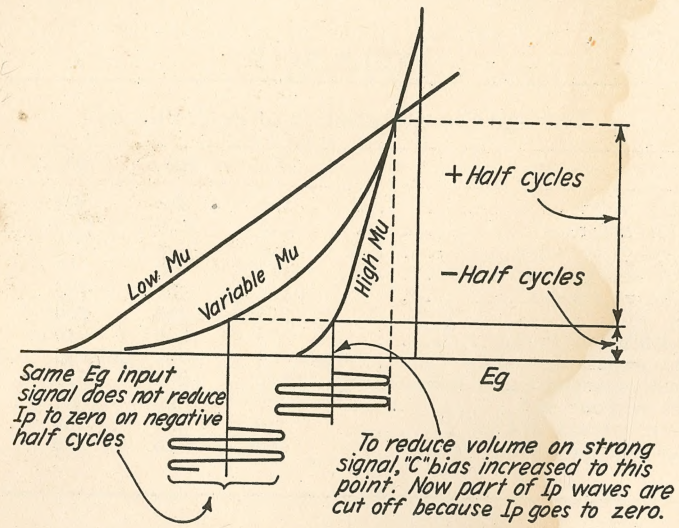

Fig. 15—Comparison of characteristics of high mu tube, low mu tube and variable mu tube.

note that the amplification factors are higher than those of the '24 type of screen grid tube while the plate resistance is less. Possibly the only reason why the R.F. pentode has not been adapted to commercial receivers is because there seems to be no especial reason for reducing the number of stages in our present receivers. There seems to be a general impression among buyers of radio receivers that the number of tubes has a great deal to do with the performance of the set. In Europe, however, where there is a tax on receivers based on the number of tubes used, there is a strong possibility that R.F. pentodes will find considerable application.

The screen grid tube was designed for one purpose—to deliver a large voltage from a small one. When it is called upon to handle a large voltage, it tries but fails. The tube is not

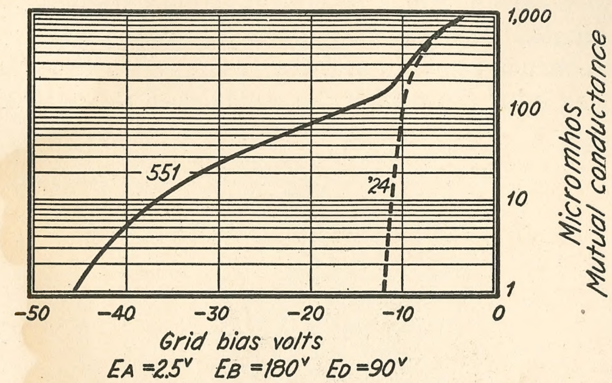

Fig. 16—Comparison of mutual conductance of variable mu and screen grid tube. Notice how much longer the variable mu tube continues to show mutual conductance.

designed for that purpose; it has a steep plate current curve so that a large voltage soon drives the plate current to zero. On the other hand a low mu tube is designed to perform another job, it takes a fairly high input voltage and delivers considerable

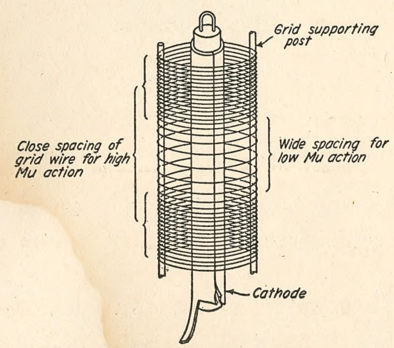

Fig. 17

power (not a large voltage) from it. It can handle a large signal, but it does not amplify voltage much.

Now consider a modern broadcast receiver, using screen grid tubes, in the vicinity of powerful broadcasting stations. Very strong voltages are induced in the antenna by waves from these nearby powerful stations. To reduce the volume to a

comfortable level the control grid bias of the screen grid tubes is increased, thereby decreasing the mutual conductance and the amplification of each stage. But in increasing the C bias we approach the zero current or cut-off point. Then on the first tube, particularly, these strong signals force the plate current to go toward zero at times causing it to act as a detector of unwanted signals. These audio signals modulate on the carrier of the station that is tuned in and the result is "cross-modulation," which "rides into" the rest of the receiver on the desired carrier

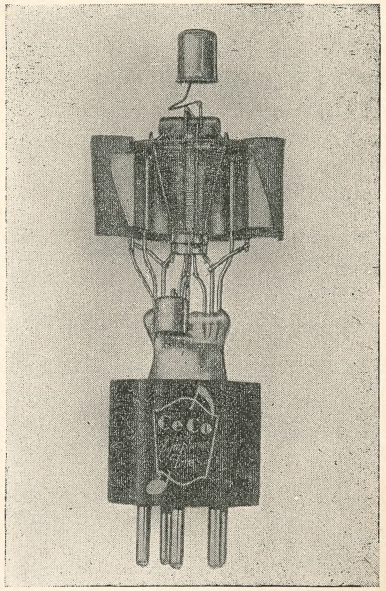

Fig. 18—Exploded view of a variable mu tube.

and finally reaches the loudspeaker, either as a signal in which the true tones are distorted or even in gasps or crashes of bits of music.

If, on the other hand, a low mu tube is used in the first stage, it can handle considerable input voltage because its grid bias can be increased to many volts before plate current cut-off occurs. (See Fig. 15.) But a low mu tube will not produce much amplification. And there is the dilemma. The hi-mu tube, such as the screen grid tube, produces the desired amplification but also distorts (modulation distortion) on strong signals. The law mu tube will handle the strong signals but produces little or no amplification.

One way to get around the difficulty is to put into the antenna circuit some volume control means. This can be done by decreasing the coupling of antenna to the first tube, or by the use of some resistance which cuts down the signals. Another way is to have a volume control working down to where the tube begins to distort and then a local-distance switch which takes care of very strong signals either by cutting out a stage of amplification, or reducing in one big step the antenna coupling. Perhaps the most common method of eliminating cross-modulation without decreased selectivity is the use of an R.F. band-pass selector before the first R.F. tube. This method will be explained in detail in a later lesson.

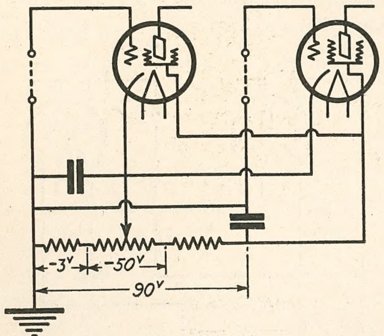

Fig. 19(a)

The idea occurred to the inventors of the variable mu tube to get around these difficulties in the following manner. The trouble with the screen grid tube is that its plate current goes to zero with large C biases. Let us shunt this tube with a low mu tube so that some plate current still flows even when the C bias is so increased that the screen grid tube no longer passes plate current. Then current cut-off does not occur, and the volume control can be worked right down to the point where the local signal has the desired level.

Such a scheme worked. But it took two tubes to do the work of one. The next step was to put two grids in the same tube, one grid being coarse like that of a low mu tube and the other fine like that of a high mu tube. At high C biases, corresponding to reduced volume control, the high mu tube ceases to pass current but the low mu part of the tube continues to pass current.

Such is the variable mu tube brought into general use in 1930-31. It is a new kind of screen grid tube with a very long characteristic such that large signal voltages do not drive the

plate current to zero on the negative half cycles with consequent distortion. In Fig. 16 will be seen the grid voltage-mutual conductance characteristic of the new tube. Note the much longer characteristic. The volume control (C bias) on local or loud signals can be greatly reduced before cut-off of plate current results.

Such characteristics are secured in an ingenious way. It is the combined curve of two tubes, one a high mu tube with a very steep characteristic and the other a long flat characteristic of a low mu tube. In one type of variable mu tube the wires of the grid are unevenly spaced as shown in Fig. 17. Then at low values of bias all of the grid is operative making it a high mu tube. At higher values of bias only part of the grid is used making it a low mu tube. Another construction is shown in Fig. 18

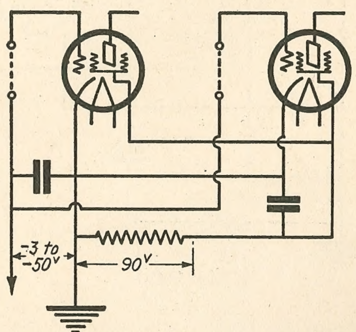

Fig. 19 (b)

where the grid is closer to the plate at one end than at another. The closer it is to the plate, the lower the mu.

The variable mu tube eliminates the need for local-distance switches and for preselecting to eliminate cross-modulation. This effects a considerable economy and simplicity of operation. In automatic volume control receivers the range of input signals over which the automatic volume control will work is increased about 25 times. The type '35 and '51 variable mu tubes will handle about 25 times the input voltage, without trouble, as a '24 tube. It is only necessary to provide the proper range of grid bias, which is not difficult. (See Fig. 19.) The tubes cannot be introduced into receivers not engineered for them and still retain the full advantages of the newer tubes. However, most receivers now made use this new tube in the R.F. stages. It is especially useful in small sets and inexpensive models where every economy of space and money must be secured.

TEST QUESTIONS

Number your answers 18FR and add your *student number*.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. Explain how the screen grid practically eliminates grid to plate capacity.

2. Why is complete shielding of tubes and stages essential in a screen grid receiver?

3. Why is actual voltage amplification obtainable from a screen grid tube used as an R.F. amplifier limited to about 1/10th the mu of the tube?

4. How is the screen grid kept at zero R.F. potential?

5. What is "secondary emission?"

6. How are the effects of secondary emission eliminated in the pentode?

7. What is the difference in the amplification factor of a variable mu tube at high signal intensities and low signal intensities?

8. How should the plate load impedance compare with the internal resistance of a power pentode?

9. What two types of distortion, common in ordering screen grid receivers, are overcome by the use of variable mu tubes?

10. Why does the use of a power pentode make unnecessary an intermediate audio amplifier stage?